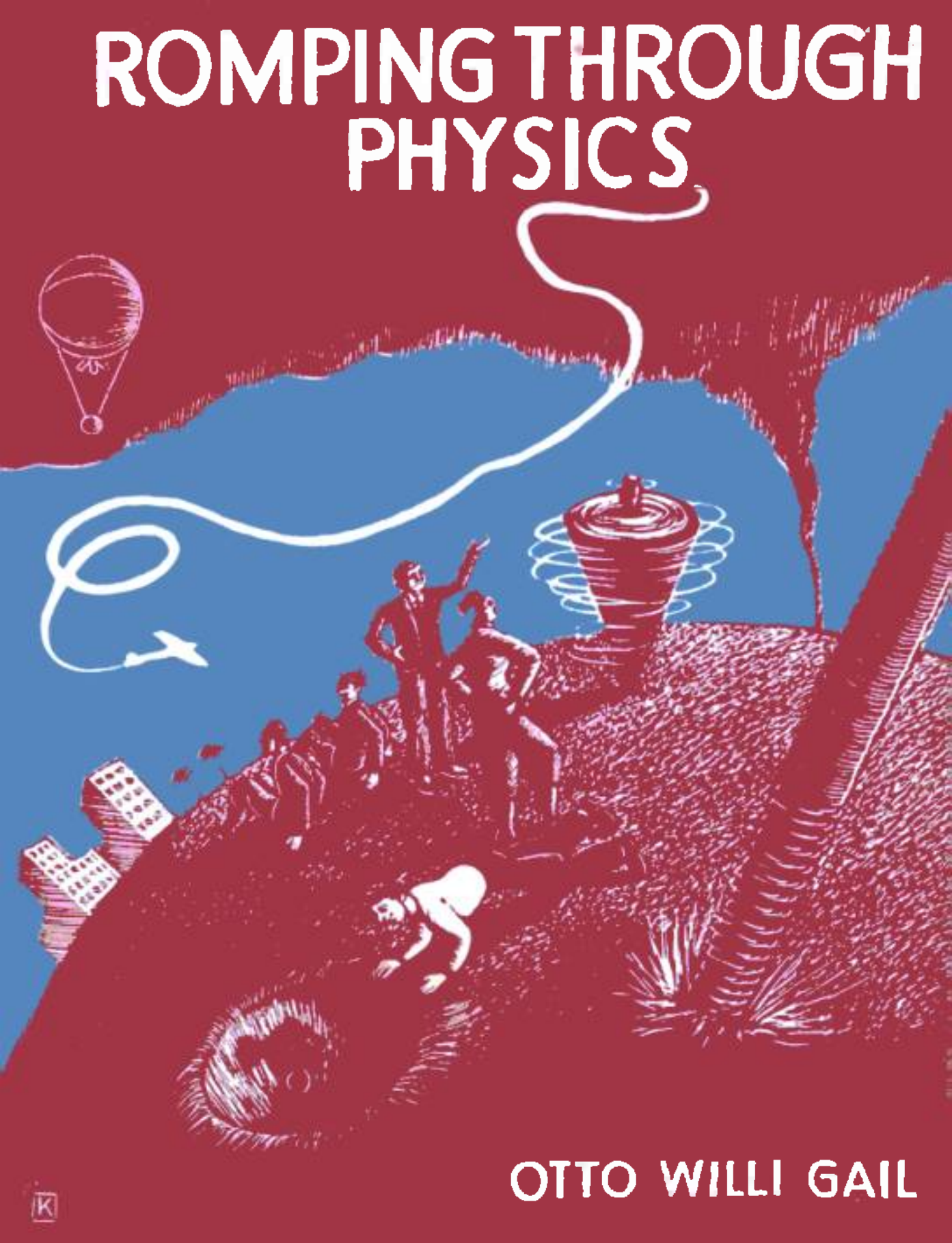
ROMPING THROUGH PHYSICS



OTTO WILLI GAIL

ROMPING THROUGH PHYSICS

It is astonishing how ignorant we are of the physical laws which govern our everyday existence. It never occurs to us to wonder what would happen if, for example, the force of gravity were suddenly suspended. Nor do we imagine the consequences if these forces, which so limit and control our daily life, could operate in different conditions. Gall, the inventor of the Rocket Propelled Car, tells us some astounding facts. We have only space here to mention some of the curious questions he answers so entertainingly: How much does a flying fly weigh? Suppose a shaft were driven through the centre of the earth and some of us dropped through it, how long would it take us to reach the other side, and what sort of experiences would we have on the way? How is it that if you stand on a weighing machine and wave your arms about, your weight is different from that which the machine records when you stand still? What would happen if a revolver could be fired in the deepest abysses of the Atlantic Ocean? These are examples picked at random, but they suffice to show the nature of this interesting book.

5s. net

ROMPING THROUGH PHYSICS

By
OTTO WILLI GAIL

With 103 Drawings by
HERMANN BLANK

LONDON
GEORGE ROUTLEDGE &
SONS, LTD.

Translated from the German by
H. STAFFORD HATFIELD

1933

First published . *November 1933*
Reprinted . *March 1934*

Printed in Great Britain by Butler & Tanner Ltd., Frome and London

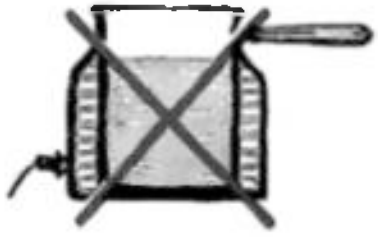
PHYSICS is a Science. If you take an interest in Science you must be able to think clearly.

MIND. All that this book asks of the reader is that he should be willing and able to use his mind.

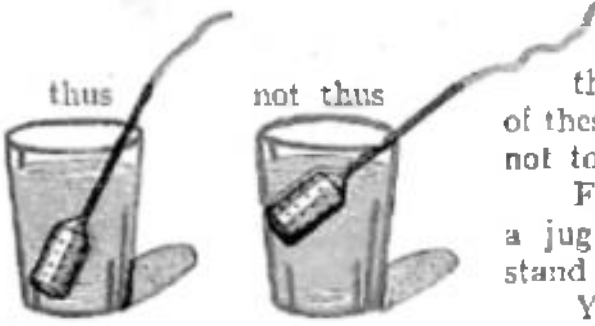
ROMPING THROUGH PHYSICS

WHEN a cook wants to heat some water, she fills a pot with it and puts it on the fire. *On* the fire, not alongside it. This is quite right, for by doing this she makes the fullest use of the source of heat. Anything that is hot is always lighter than the same thing when cold, and so it rises upwards. The air heated by the fire rises upwards, and surrounds the pot like a warm coat. In the same way, the water at the bottom of the pot (which is hot) gets heated first and rises upwards, while the cooler water flows down to the bottom of the pot and gets heated in its turn; this goes on until the whole potful boils.

So, if we want to heat a liquid, the fire or other source of heat should always be underneath it. This is the reason why the heating arrangements of electric saucepans are always at the bottom. An electric saucepan with its heating arrangement at the side is a bad one, because it uses too much current.



Also, an ' immersion-heater ' works better, the deeper it is plunged into the liquid—



All this is quite obvious. And so it is all the more surprising that people often take no notice of these simple laws when they want, not to heat, but to cool a liquid.

For example, if you want to cool a jug of lemonade, you generally stand it on ice.

You put it *on* the source of cold, just as the pot is put *on* the source of heat. But, of course, this is entirely wrong. For, in cooling, the flow is in exactly the opposite direction. What is cold flows downwards, not upwards, and the lemonade-jug is no exception to this rule. When it is put on ice, the lowest layer of the liquid is quite well cooled, but it takes a long time for the cold to reach the upper layer of the liquid. For the air which is cooled by the ice flows *downwards*, while fresh warm air continues to flow over the jug from every direction. So the greater part of the jug does not get cooled. If you want to get the maximum cooling with the minimum amount of ice, you must proceed according to the next picture. The ice must be put *on top* of the jug ; and if the jug has no lid you must put a saucer on it. It is astonishing how quickly a jug can be cooled in this way. For first the top layer of the liquid is cooled : this sinks downwards because it becomes heavier, and immediately the next layer is cooled in turn

and also sinks downwards. Thus the whole contents of the jug are quickly cooled. Also the air which is cooled by the ice sinks, and flows all round the jug.

There is no reason why the physicist should not take an interest in household matters. So here is another kitchen problem.

Our guests are late, and we want to keep the coffee hot. How are we to do this? A tea-cosy will not keep it hot long enough, and it is a mistake to put the coffee on the stove or the gas-ring, because it might boil—and that would spoil its taste completely. In a case like this an experienced housewife puts the coffee-pot in a 'water-bath'—that is, in a large saucepan filled with water and placed on the gas. If she is careful to fix the pot in the saucepan in such a way that it does not touch the bottom, she can quite safely leave the whole affair to take

care of itself. The coffee keeps extremely hot, but it will never boil, no matter how violently the water in the pan outside it may be boiling.

Why is this? In order to make a liquid boil, it is not sufficient to heat it up to boiling-point: a great deal of additional heat must be given to it. This extra heat does not raise the temperature of the liquid, but is consumed in producing vapour. The water in the pot gets its heat from the fire, the gas, or the electric current, as the case

may be. When it boils, it is at 'boiling-point', and it cannot get any hotter than 100 degrees 'Centigrade', or 212 degrees 'Fahrenheit'.[1]

Heat passes gradually into the coffee-pot from the water in the saucepan, until the temperature of the coffee is the same as that of the water. After that the heat stops flowing into the coffee, because heat can only flow when there is some difference of temperatures, and only from a hotter to a cooler place. The coffee cannot boil, because it simply does not get the extra heat which it requires in order to do so.

And so now we can see why it is that the coffee-pot ought not to touch the bottom of the saucepan. It should receive heat only from the water which surrounds it, since the water cannot rise above boiling-point (or 100 degrees), whereas the bottom of the saucepan can get very much hotter than this. Then the heat would be able to pass directly from the bottom of the saucepan into the coffee-pot and the coffee would start boiling merrily.

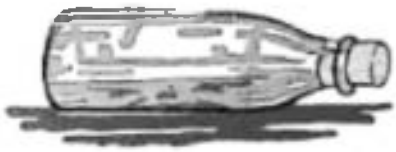
But it is quite easy to play a naughty trick on our good housewife. We only have to throw a handful of salt into the saucepan to change matters entirely. For salt and water has a higher boiling-point than plain water, and so gets hotter than 100 degrees. In this way the heat does not stop passing into the coffee when the coffee reaches boiling-point, so that it boils just as if the pot were standing on the bottom of the saucepan.

However, I haven't told you this in order to teach you to annoy your mother or tease the cook, but because we can use boiling salt water to perform an interesting and surprising experiment. We can make snow or ice boil water. That sounds incredible, but it is perfectly true.

Let us take the saucepan that we were using as a water-bath for keeping the coffee hot, and let us now put into it, not the coffee-pot, but a bottle filled with water. We know already that the water will

[1] In England and America we make things more difficult for ourselves than we need, by using two quite different scales to measure temperature. One is quite a simple one, used by scientists, and called 'Centigrade': on this scale ice melts at 'zero', or 0 degrees, and water boils at 100 degrees. The other is an old-fashioned and inconvenient scale called 'Fahrenheit': on it, ice melts at 32 degrees and water boils at 212 degrees. This scale is much used by engineers, doctors, and also by the 'Clerk of the Weather'. A Fahrenheit degree is only five-ninths of a Centigrade degree.

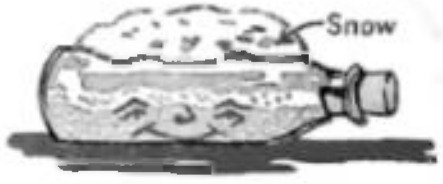
get very hot, but will not boil. But let us make it boil by standing the bottle right on the bottom of the saucepan, and also by adding a handful of salt to the water in the saucepan. After a while both the water in the saucepan and the water in the bottle will boil. We then take the bottle out of the saucepan, pour out half of the water



that there is in it and immediately cork it tightly with a close-fitting cork. Now, if we lay it on its side, the water in it will be quite still for it has long ago stopped boiling.

Now let us put a handful of snow or crushed ice on the top of the bottle. What happens to the water in it? It immediately starts to boil again, and goes on doing so.

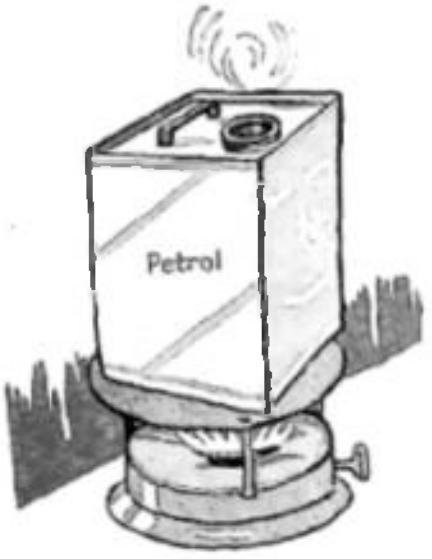
This seems very extraordinary. The cold snow accomplishes in a moment the thing which hours of boiling in an unsalted water-bath would have failed to do. Certainly it seems a riddle—and all the more so because the bottle no longer feels hot, but only lukewarm, though we can see with our own eyes that the water in it is boiling.



This is how it happens. When we corked up the bottle, it contained only hot water and steam; the air had nearly all been driven out by the steam. Now the snow makes the sides of the bottle very cold; the steam does not like that at all, and shrinks together into little drops of water—condenses, as we say. (That, by the way, is how rain is formed: but that's another story.) The steam in the bottle thus disappears, for the most part, by condensation, and the space above the water is left empty both of air and steam—it is nearly a 'vacuum', as it is called. So we no longer have the normal pressure of the air in the bottle, but only quite a small pressure of water-vapour.

That is why the water boils again. For, the lower the pressure on the water, the lower the temperature at which it boils. The water, although it has cooled down quite a lot, is still warm enough to boil at the lower pressure.

If the bottle is very thin, it may break if it is cooled too suddenly. For when the pressure inside becomes very low owing to the condensation of the steam, the pressure of the air on the outside of the bottle may be enough to shatter it. It is therefore a good plan to use a round bottle for the experiment, not a square or a flat one, as the round shape is much better able to stand the pressure.

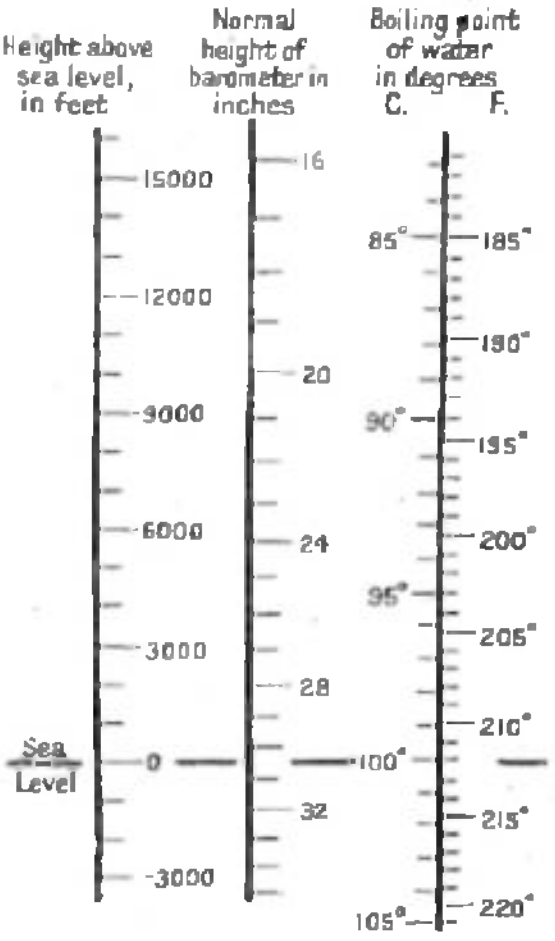


The effect of air pressure can be seen very well if, instead of a bottle, we use an empty petrol tin, such as we can easily get at any garage.

Boil a little water in it, and when the steam is coming out freely take it off the fire, and immediately screw the stopper on tightly. Then pour some cold water on the tin; it is immediately squashed flat by the air pressure, just as if it had had a blow with a heavy hammer.

This fact—that, the lower the pressure of the air, the lower the temperature at which water boils—is used to measure the height of places above the sea level, by means of an ordinary thermometer.

The higher you go, the lower the pressure of the air—the atmospheric pressure, as it is called. If you look at the scales drawn here side by side, you can see just how the height of the barometer (which measures the atmospheric pressure) and the boiling-point of water vary with the height above sea level.



To find out how high above sea level you are, you have only to boil some water and measure the temperature at which it boils: then look at the scales and find the height above sea level corresponding to this temperature.

It is quite wrong, therefore, to imagine that boiling water must

always be very hot. On the top of Mont Blanc, for example, it boils at 84 degrees Centigrade, and the man in charge of the weather station up there can never make good tea or coffee, for he cannot get the water hot enough. On the planet Mars, whose thin covering of air only has a pressure of about 2½ inches of mercury, the water would only just get lukewarm when it boiled, while under the receiver of an air-pump water will boil at ordinary temperature, if we make a good enough vacuum by means of the pump.

On the other hand, in deep mines the pressure of the air is considerably higher than on the surface of the earth, and so boiling water is hotter down there. The boiling-point rises about 1 degree Centigrade for every 1000 feet you go down. The miner who boils eggs down in the mine has to be careful if he does not want them too hard, for they will take a shorter time to cook than at home.

Talking of eggs, what is a cook to do if she mixes up a lot of boiled eggs with some raw eggs? How can you tell whether an egg is boiled or raw? Generally, people hold the egg up to the light;

a raw egg allows just a little light to shine through. But this method is not quite trustworthy, for when an egg is really and truly 'new-laid' it also will not let any light pass through. A little physics will teach you what to do to make sure.

You can tell a raw egg from a boiled egg from the way it spins. To test an egg, put it on the table and give it a spin with your finger and thumb, like a top. This tells you at once what you want to know, for an unboiled egg is lazy and stops spinning almost at once. In fact, it is quite difficult to get a raw egg to spin at all. But a boiled egg, especially if it is boiled quite hard, can be made to spin easily and so quickly that it seems to lose its shape and turn into a round disc as you look at it. And it goes on spinning for some time.

The reason of this is that a boiled egg is a solid mass right through, and so all its parts can be set spinning together. But the liquid inside the raw egg does not start spinning along with the shell, on account of its inertia; it acts as a brake and stops the egg spinning altogether.

A very pretty experiment can also be made by using neither a boiled nor a raw egg, but an egg-shell out of which the inside has been carefully sucked or blown. The shell, after spinning in its side for a moment, stands up all by itself and spins on its point.

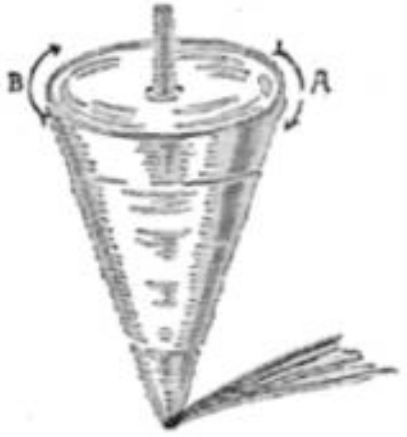
Columbus [illegible] about this, as he would have done, thought it necessary [illegible] dent in the egg in order to make it stand up.

* * * * *

Now why doesn't the egg fall over [illegible]

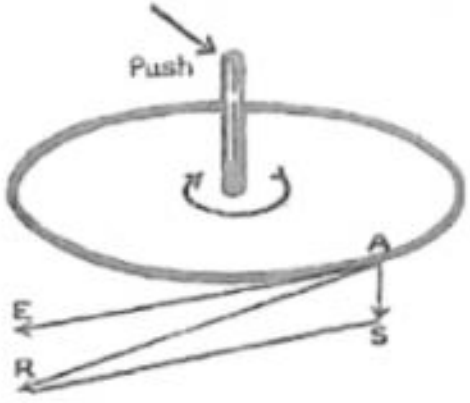
point? Because it is just like a top, of course! But why doesn't a top fall over?

Out of a thousand people who have played with tops when they were children there is hardly one who can answer this question correctly. It is really a very curious thing that a top standing on its point, or even leaning slightly sideways, should remain balanced and not fall over. What is the force that holds it in this unnatural position? Has 'gravity'—the force of the Earth which pulls all heavy bodies downwards—no effect on the top when it is spinning?



The theory of the top is not altogether easy. As we do not want to lose ourselves in tedious demonstrations, we will simply give our attention to the main reason why the top does not fall over.

Here is a picture of a top, which is turning round in the direction of the arrow. The point A is coming towards you, the point B is going away from you. If we push the spindle over towards the right, the point B gets pushed upwards, the point A is pushed downwards.



Let us now follow the movement of the point A. Added to its own movement (E), there is the downward movement (S), which is caused by the push. These combine to form the resultant movement R.

But the top's own movement (E) is very considerable, since it is spinning quickly compared with the slight sideways movement (S) —much more considerable, in fact, than the drawing shows. We have a resulting movement which is so little different from the original movement (E) that the motion does not appear to change. In this

way we get the impression that the top actually resists being upset. And the heavier it is, and the faster it is spinning, the greater its resistance, even to quite powerful pushes.

This same explanation also holds good in the case of many other effects that can be seen every day. A child bowling a hoop, for instance, makes use, without knowing it, of this property which revolving bodies possess—the property of resisting every change in the direction of the axis of rotation.

The game of Diabolo depends on the same principle. The string is used, first to set the double-ended top spinning quickly, and then to throw it up high into the air. But while it is in the air it keeps unchanged the direction of the axis round which it is spinning, and so it is not difficult to catch it again with the string stretched. If the Diabolo were not spinning, the cleverest juggler in the world could not play with it like this.

The same is true of Yo-yo. Unless it is spinning quickly, it is impossible to do anything with it.

If you want to throw someone a hat in such a way that he can catch it on his head, it is no use simply throwing it straight at him;

it will turn over and over in the air and will land the right way up only by the merest chance. But if you give the hat a quick spin

just as it leaves your hand, it keeps its position as it travels through the air and is much easier to catch.

This dodge of giving things a spin is used by all jugglers. They know of the astonishing persistence of spinning objects in resisting any change of position. It is for the same reason also that the barrels of guns are made with spiral grooves inside; these give the bullet or shell, as it travels down the barrel, a quick spinning motion which prevents it from turning over and over in the air during its flight. This makes the aim much more accurate.

We started by talking about hot water and have arrived by all sorts of roundabout ways at spinning tops. But we will keep to this subject for a little, not forgetting the experiment with a pail of water slung round on a string. In this experiment, if you whirl the pail

round fast enough, not a drop of water will be spilt, even when the pail is upside down.

How does this happen? 'centrifugal force', we say, meaning by that a mysterious force which causes bodies, as it were, to fly away from the point about which they are turning. But there is really no such force. This tendency is simply 'inertia'—the Latin word for laziness—and this meaning of the word can be taken quite literally. All bodies are 'lazy'; they do not like having their rest disturbed. And when once they possess a motion of any kind, they also resist any attempt to change this motion in any way, either as regards speed

or direction. They want to go on moving in exactly the same way. This property which all bodies possess is called 'momentum'. You may often hear it said that a heavy body in motion—a car, or a man running—has a lot of momentum; by which it is meant that a lot of force would be needed to bring it to a standstill. Thus momentum is the result of inertia.

If we are going to explain the experiment with the pail by means of inertia, the first question to ask is: In what direction would the water spurt out if we made a hole in the pail? If there were no force of gravity drawing the water down towards the Earth, the water would

spurt out of the pail straight along the line of a tangent to the circle in which the pail is moving, and in the form of a straight jet. But under the influence of gravity the jet would turn downwards into a parabola (P). And if the speed is great enough, this parabola lies right outside the circle in which the pail is moving.

This, therefore, is the direction in which the water would escape if the pail were not holding it fast. We can see at once that the water does not tend to fall straight down to the ground; it has, therefore, no reason to fall straight out of the pail. That could only happen if the pail were swung round with the open end in front, thus:

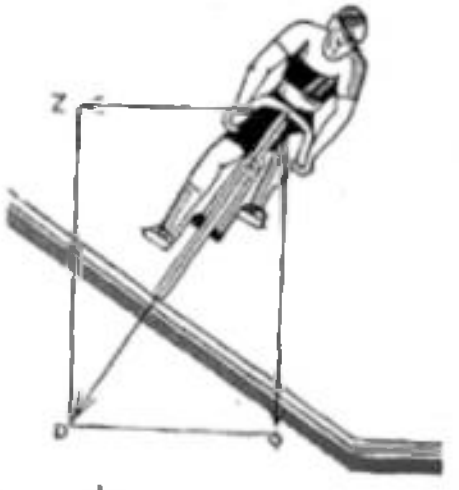
It is possible to calculate the rate at which it is necessary to twirl the pail round: it works out at about 1½ turns per second. At this speed, the parabola along which the water would flow lies outside the circle in which the pail moves, and the water does not spill out. This speed is easily attained; hence the experiment is nearly always successful.

To return once more to centrifugal force, which is so often misunderstood. The force with which the water presses on the bottom of the pail, or the force which the pail exerts on the string, is often called centrifugal force. This force, however, is not a cause, but a self-evident result. Because the water is forced, contrary to its natural inertia, to travel round in a circle along with the pail, we get a centrifugal force directed outwards from the centre. This force, therefore, is simply the peculiar way in which the inertia of the water makes itself felt.

For example, in the case of the cyclist in the picture who is travelling round the bend of a racing-track, the speed at which he is travelling results in a centrifugal force (Z) directed outwards from the centre of the circle in which he is travelling. But since there is, in addition, his own weight (which acts directly downwards) the two forces result in a pressure (D) on the track. This pressure is directed outwards and sideways. The track must slope so that it is at right-angles to

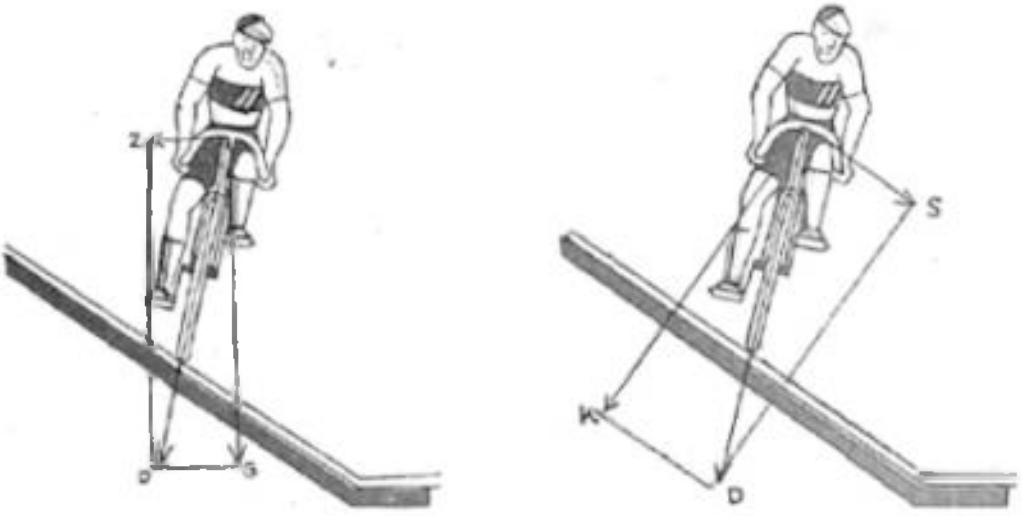
this pressure and can therefore meet it properly. This sloping of the track is called ' banking '.

The picture introduces us to the well-known ' parallelogram of forces '. If two forces act upon an object (in this case the forces Z and G) the result—or ' resultant ', as it is called in scientific language—is a single force which can be found by drawing a line to represent the amount and direction of each force, and then drawing two more lines to complete a parallelogram. The diagonal of this parallelogram then represents the ' resultant ' force, both as regards its direction and its amount, on the same scale.

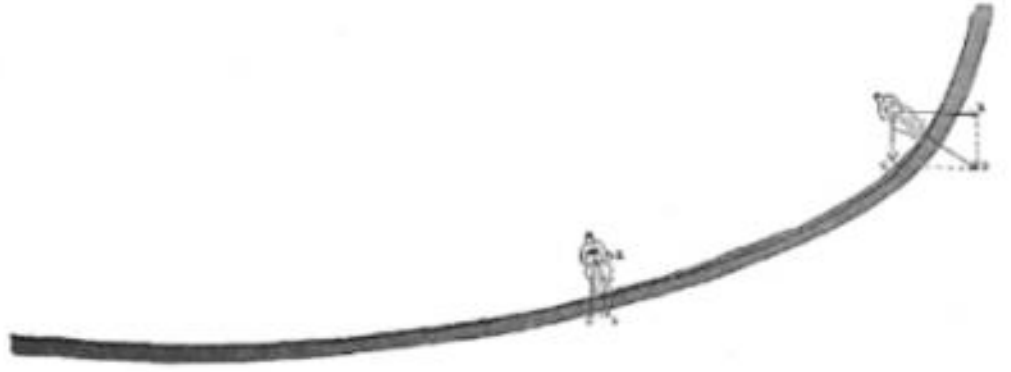


The banking of the track can only be *exactly* right for one particular speed. If the cyclist is travelling slower than this, the centri-

fugal force is too small, and the resultant pressure is no longer at right-angles to the surface of the track. It can at once be seen to be tending slightly inwards, and will thus produce a tendency for the cyclist to side-slip inwards.



In the opposite case—that is, if the cyclist is going faster than the speed for which the banking is calculated—the banking is not steep enough and the cyclist tends to side-slip outwards, just as he does on a flat road, but of course not so much.



Big motor-racing tracks, therefore, are built so as to increase in steepness towards the edge. On such a track there is no limit to the

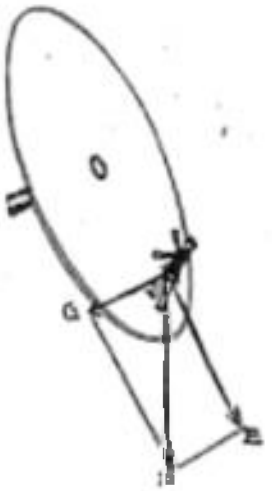
speed that is possible. The faster the car travels, the nearer it goes to the outside edge of the track, where it is steeper. Thus the driver is always able to find a place where there is no tendency to side-slip.

If the curve of the track is very sharp and the speed very high, the centrifugal force may become so great that the force of gravity is quite small compared with it. The car can then travel safely along an almost vertical wall.

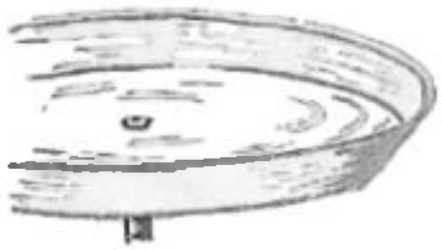
The curious thing is that this wall appears to the driver to be almost horizontal. For he feels his own weight in the direction of the resultant pressure D; and the direction in which he feels his own weight to be acting appears to him to be vertical, whatever his real position may be.

A less dangerous opportunity of experiencing this illusion is afforded by the 'joy-wheels' which are often to be found at Fairs and Exhibitions. These are really turn-tables, very much like those which are used on the railway to turn locomotives round; but they are turned very much faster—faster and faster until all the people sitting or standing on them are thrown off by centrifugal force. When you go for a ride on one of them, this force makes you conscious of

your own inertia. If you close your eyes while you are still able to stand upright on the moving turn-table, you completely lose the feeling that you are standing on a flat surface. You imagine the turntable to be sloping, and that your tendency to slip outwards is caused by the slope.



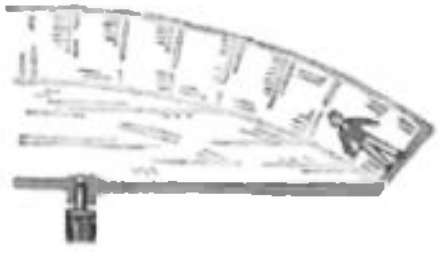
The reason for this can also be shown by means of the parallelogram of forces, just as in the case of the cyclist.



Now imagine that the edge of the turn-table is bent upwards. This edge would give a person who is slipping off a chance to hang on; he would be able to stand upright on it without difficulty.

What really happens is shown in the next picture. A person can stand on the sloping edge (for it really *is* sloping), but he would feel as if he were on a horizontal surface.

A little consideration brings us



to an almost fantastic possibility. We have imagined the turn-table as being flat, with a sloping rim. The passenger slides out-

wards along the flat surface until he reaches the rim, where he can stand upright. 'Is it possible to make the surface of the disc of such a shape that he can stand up anywhere on it, and feel, wherever he is, that he is standing on a flat, horizontal surface?

Yes, such a shape is possible. It is something like that of a wineglass, and is called by mathematicians a 'paraboloid', since it is the surface produced when the curve called a 'parabola' is revolved round its axis.

It is quite easy to make a surface like this. Take a wine-glass, half-fill it with hot melted wax, and set it exactly in the centre of the turn-table of a gramophone.

Start the gramophone, and you will see that the liquid wax sinks down in the middle and climbs up the sides of the glass.

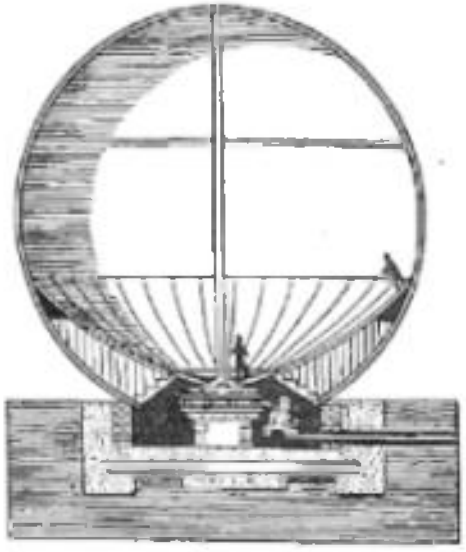
Let the glass go on turning steadily until the wax has cooled and set solid; then take away the glass and you will find in it the paraboloid surface which we wanted—and mathematically exact, too.

Now set the glass on the gramophone, start it going at the same speed as before, and put in it a small steel bicycle ball. You will then be surprised to find that the ball will remain steady at any point inside the glass, without rolling down the side of the glass to the lowest

point. This is because, at every point on the paraboloid surface, the resultant of gravity and centrifugal force is directed at right angles

to the surface of the wax in the glass, and the ball has thus no reason to change its position. If it were alive, it would feel at every point as if it were standing on a horizontal surface.

An enterprising American once made a contrivance which was both amusing and instructive, for it made it possible for people actually to experience the situation of the steel ball in the waxed wine-glass. He built a room in the form of a huge globe, making the floor of just the correct paraboloid shape, and visitors to it experience sensations such as are usually to be felt only in dreams.



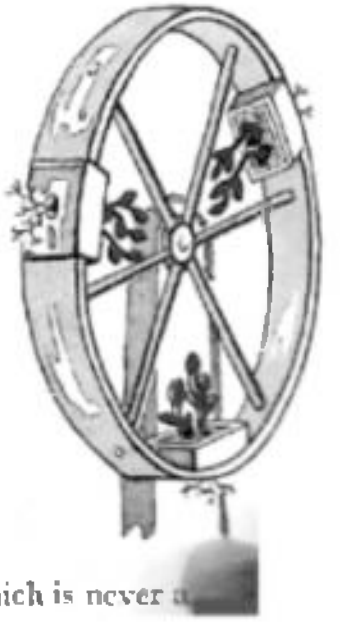
The floor of the globe is a large paraboloid surface, just like that of the wax of which we have been talking. The walls are opaque, so that people inside are not aware that the whole contrivance is revolving and so do not get giddy. Only two people are allowed inside the globe at once. Then the power is turned on, and the globe rotates. When the correct speed is reached, the people inside feel that the floor under their feet is

horizontal, whether they are standing at the centre, where it really is horizontal, or on the sides, which in reality have a steep slope.

The eye is aware of the curvature, but the muscular sense denies its existence, the two senses contradicting one another. Each of the

people inside looks to his companion as if he were walking on a steep slope, like a fly.

If water is thrown on the floor of the globe, it covers it uniformly in a thin layer, so that the people inside enjoy the very unusual sight of a sloping water surface. And since, at any point inside the globe, they have the sensation that *they* are standing upright while everything else is on a curve, they have only to run across the globe from one side to another in order to feel as if the whole thing had turned round under their feet like a soap-bubble.



Inside this magic globe all ordinary notions of inertia and gravity are turned upside down, and the centrifugal force of inertia makes you feel as if you were living in a fairy-story.

Plants, by the way, are just as capable of being deceived in this way as people are. Young plants, as you know, always grow 'upwards'; that is to say, they direct their stems *against* gravity. But if a plant is allowed to come up from seed in soil that is stuck on to the rim of a fast-rotating wheel which is never a

stop, a surprising thing happens. The roots grow outwards from the centre of the wheel, while the stem comes up *towards* the centre.

The plant has thus been cheated; centrifugal force has been used to produce a false force of gravity, and the plant, knowing no better, has adapted itself accordingly. The English botanist Knight did these experiments in plant-deception over a hundred years ago.

Some of the sensations produced in the magic globe of which we have spoken (I don't think such a globe exists in England) can also be experienced by anyone who flies round a curve in a fast aeroplane.

The machine, as it takes the curve, actually gets into a position like this:

It 'banks',—that is to say, it tilts sideways exactly as much as a car would do when taking the same curve at the same speed on a track correctly sloped for that particular speed.

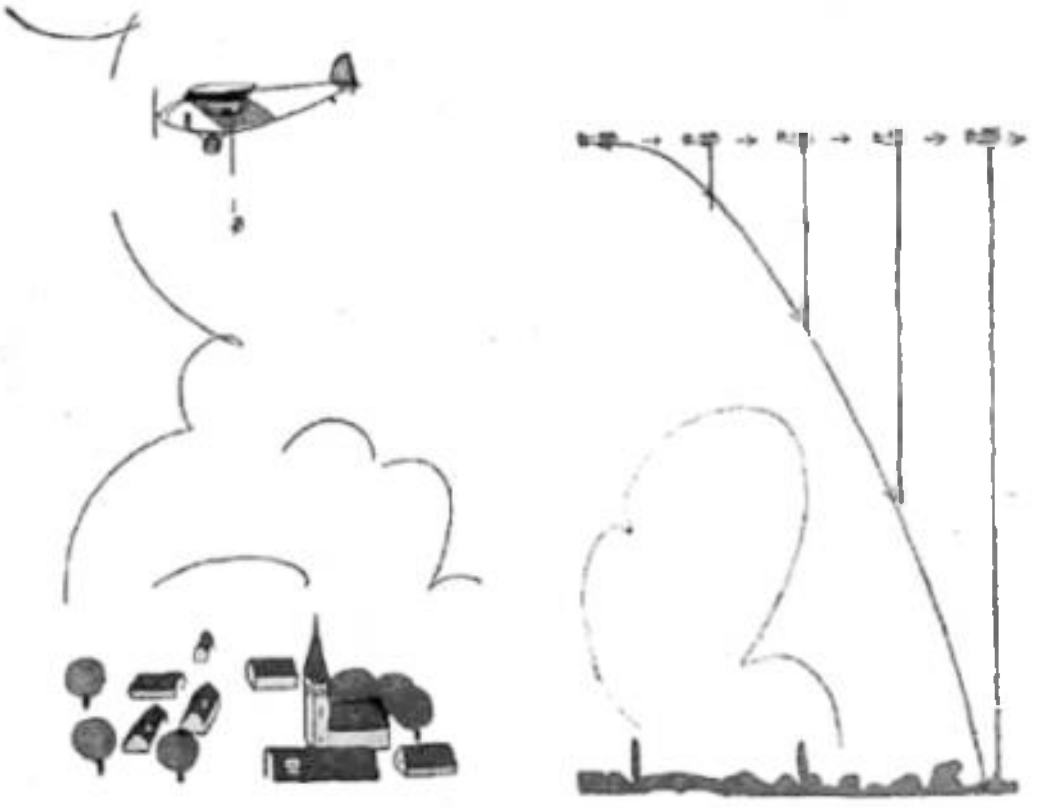
But the passenger in the aeroplane is not in the least conscious of this change of position; he is surprised to see the surface of the earth suddenly turn up into a steep slope.

He gets the impression that, if he were to throw a ball out of the aeroplane, it would fall past the Earth and be lost in limitless space. But if he tried the experiment, he would be astonished to see the ball shoot sideways towards the Earth's surface, instead of falling in the direction which he imagines to be downwards.

How does an object thrown out of an aeroplane travel?

There is a certain popular poet who is fond of flying, and who is also fully aware of the uses of advertisement. It is his custom, when flying over a large town, to throw out a bouquet of flowers with

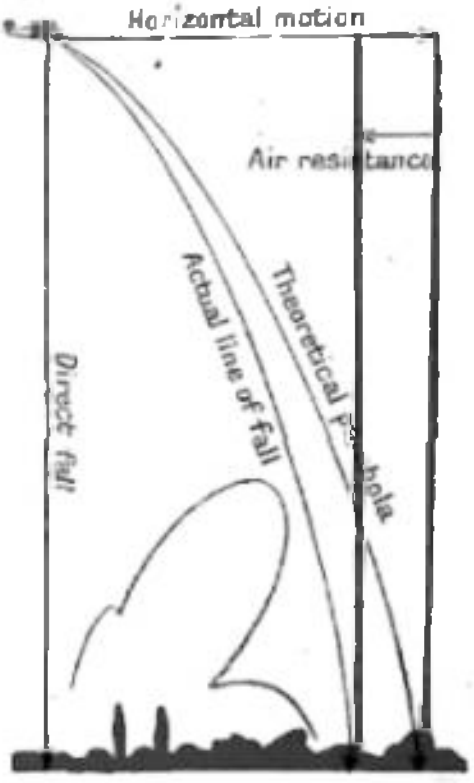
a card of greetings from himself to the finder attached to it. But he often finds it very difficult to make the flowers land in the right place when they are thrown from the swiftly-moving aeroplane. If he wants the flowers to land in the principal square of the town and throws them out when it is exactly below him, they will certainly not reach the spot he is aiming at, but will travel far beyond it.



If you look out of the aeroplane at the falling object, you will be surprised to see that, though it falls downwards, it also travels along with the aeroplane as it falls. In fact, it almost keeps up with it. The little distance that it falls behind is due to the resistance of the air; if the air did not hold it back it would remain always exactly underneath the aeroplane, and would fall as if it were sliding down an invisible thread hanging down vertically from the aeroplane.

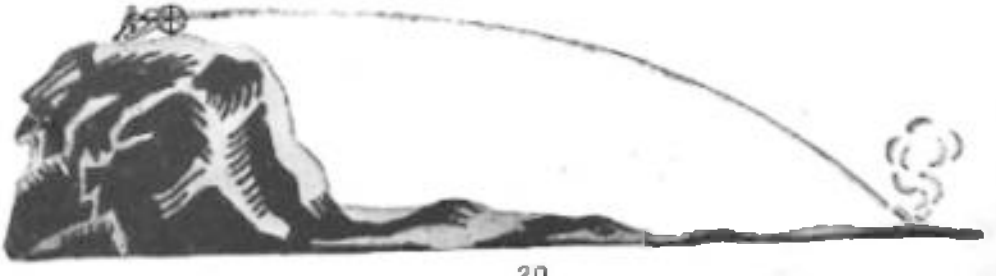
The reason for this is, once more, inertia. As long as the bouquet

was in the aeroplane, it of course travelled along with it in a horizontal direction. As soon as it was allowed to fall out, it became separated from the aeroplane, but that is no reason why it should give up its horizontal motion. This motion continues as before, and combines with the motion of falling (which gets faster and faster) to form the curve called a 'parabola'. This, then, is the curve along which the bouquet of flowers would travel if there were no air-resistance to check it.



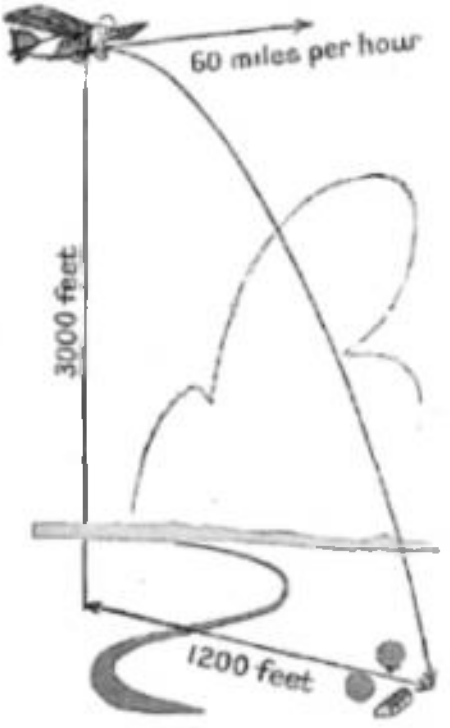
But the air-resistance bends the parabola back to a certain extent, making it steeper, and this steeper curve is the one followed by the flowers.

The bouquet of flowers, in fact, behaves in exactly the same way as a shell shot out of a gun set up on a high cliff and firing horizontally. The shell describes a curve which ends on the ground. But the speed of the shell being much greater than that of the aeroplane, its path is much longer. The shell and the flowers fall downwards at the same rate, and so take the same time to reach the ground from the same height. But, during this time, the shell travels farther in a horizontal direction.



The effect of air-resistance is not the same for every object. The lighter the object as compared with its surface, the greater the air-resistance. For instance, a sheet of paper lags behind the aeroplane much more than the flowers, while a heavy stone will follow the motion of the aeroplane with very little lag.

It can be seen, therefore, that our friend the poet, if he wants his flowers to land in the middle of the town, must throw them out before the aeroplane is flying over it—in fact, well before, if the aero-



plane is flying high. The distance may be very considerable. If an aeroplane is flying at a height of 3000 feet, and at a speed of 60 miles per hour, the flowers will fall nearly 1200 feet from the point over which they are thrown out.

In this way we can form some idea of how difficult it is for an airman to hit a given mark with a bomb. He must take all sorts of things into consideration—the speed of his aeroplane, the resistance of the air to the falling bomb, and the effect of the wind. If there

is no wind, the bomb will fall in the normal way (F). If the wind is behind the machine, the latter travels faster, and so does the bomb; hence it will travel farther from the perpendicular direction, and describe, say, the line V. The bomb, of course, will never travel faster than the following wind, however strong.

With a head wind, the bomb does not travel so far from the vertical; its line would be, say, along Z. But if the wind, as often happens, is different, and even opposite, in direction at different

heights, the path of the falling bomb will be very complicated and perhaps impossible to calculate. So, when the next war comes along, there are just a few chances that some of us may escape with our lives!

Remember that what we have just been saying applies only when the 'air-speed' of the aeroplane is the same in every case. (The 'air-speed' is the rate of travel through the air.) But we could imagine a case when the aeroplane is flying against a wind which

has exactly the same speed as itself. The aeroplane would then be stationary in the sky, and the bomb would fall almost vertically—along S, say. The wind, of course, would bend back the path of its fall a little. But this case does not often occur; aeroplanes do not go up in hurricanes blowing at 80 miles per hour, if they can help it.

Now we come to a question which, on the face of it, seems almost nonsensical: why does the bomb fall down to the Earth?—Naturally, you say, because the Earth attracts the bomb, and this attraction gives it its weight.

But be careful about this matter of weight. Does the bomb really possess weight? Certainly, as long as it is hanging on the aeroplane. But has it weight while it is falling? In short, what is the weight of a falling body?

Before answering this, let us try an experiment.

In one pan of a pair of scales we have a pair of nutcrackers. One leg of the nutcrackers is tied by a thread to the beam of the scales. In the other pan we put weights which exactly balance the weight of the nutcrackers. We then put a lighted match to the thread, which makes the nutcrackers suddenly close up.

What happens to the scales while the leg of the crackers is actually falling? That is easy to guess; the pan with the weights sinks, the pan with the nutcrackers rises, because the nutcrackers become lighter for the instant during which the leg is falling. And why? Because the leg, while it is falling, weighs nothing.

Another example. If you put a pound weight on a spring scale, the pointer turns to 1 lb.—provided the balance is a good one.

If you then take the balance in your hands and lower it quickly

and suddenly, its pointer goes back quite a considerable distance towards zero while the motion is taking place.

If it were possible to let the balance fall quite freely and to observe

the pointer while it was doing so, you would see that the pound weight ceases to have any significance while it is falling. The pointer stands at zero.

This is not an illusion, for a falling body actually has no weight.

What we call 'weight' is the force with which a body presses upon whatever is supporting it; or, if it is hanging, the pull which it exerts upon the cord or chain or whatever is holding it. But when a body is falling freely it has no support upon which it can press—not even when it is lying in the pan of a balance. For the balance is also falling downwards at the same speed.

This is what Galileo, the founder of Mechanics, wrote in the sixteenth century: 'We feel a load upon our shoulders, when we prevent it from falling to the ground; but if we move downwards at the same speed as the load, how can it press upon us? This is the same thing as if we should try to stick a spear into the back of a man running away from us as fast as we ourselves are running.'

Everyone who has travelled in a lift knows the peculiar and not very pleasant sensation that one feels as the lift starts to go down. It is just as if one were falling down a precipice, and it often makes sensitive people feel quite sick.

This is simply the unaccustomed feeling of being without weight. When the lift starts, or the floor falls away from under one's feet, one's body has not had time to attain, by falling, to the same speed as the lift, and therefore does not press upon the floor. Hence it has no weight, or only very little. But the sensation does not last long, for the body, like every object that is falling freely, tends to fall faster and faster; so it soon overtakes the lift and again presses on the floor, thus recovering its proper weight.

If, however, the lift did not travel downwards at a steady speed,

but kept on gathering speed as a freely-falling object would (that is, travelling 32 feet per second faster at the end of every second), the sensation of being without weight would continue, and the passengers would be able to move about in the little cabin as though they were angels without weight.

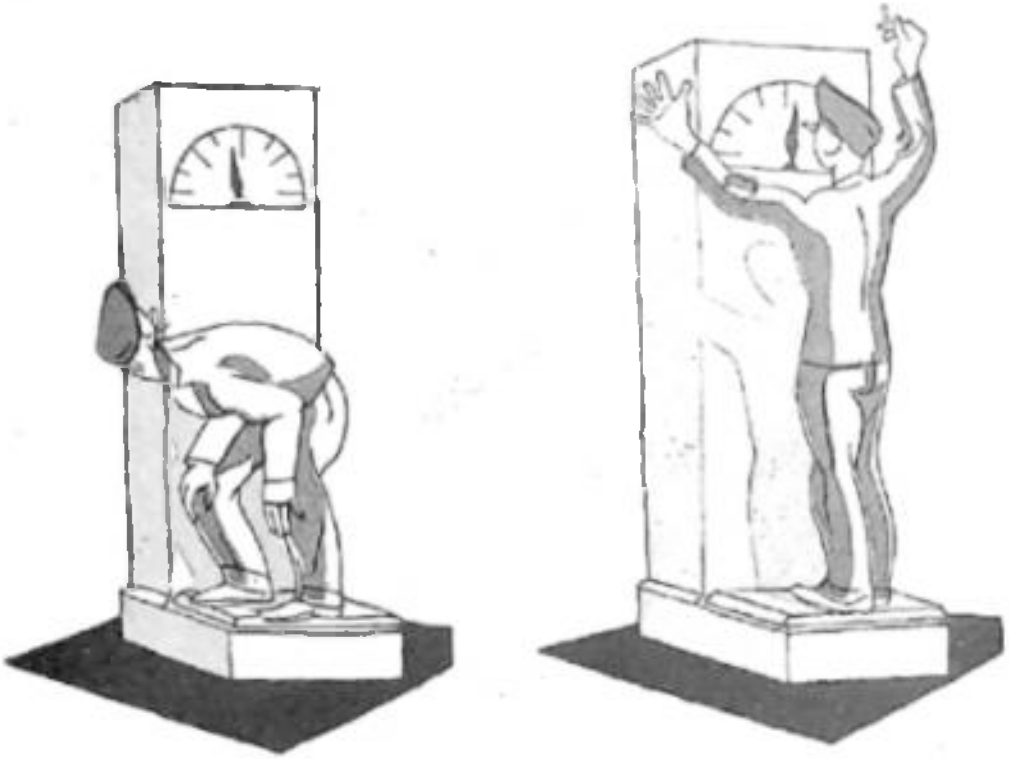
But as soon as the acceleration stopped and the motion of the lift became steady (no matter how fast it might then be), the 'angels' would at once fall to the floor and recover their normal weight.[1]

The fact that the weight of our bodies is not constant, but depends upon our motion, can be easily shown by means of an ordinary weighing-machine. The latter only gives our correct weight if we stand quite still upon it. If we stoop down, the weight shown by the pointer becomes a little less while we are actually moving. But when we stop the downward movement, we do more than recover our normal weight; the machine shows, for a moment, a greater weight than the correct one.

[1] Jules Verne, in his book *A Journey to the Moon*, and H. G. Wells, in his *First Men in the Moon*, describe the weightlessness of their travellers when they get away from the Earth's attraction.

Why is this?

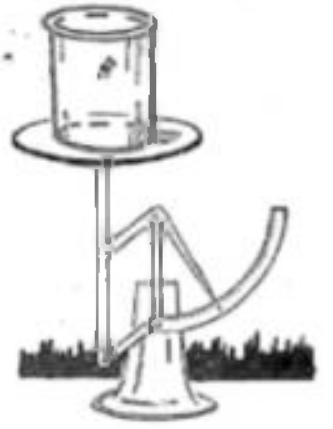
The muscles which bend the upper part of the body downwards also pull on the lower part of the body. This lessens the pressure of the body on the weighing-machine. When the downward movement of the trunk is checked, the muscles must act against it, in such a way as to press the upper and lower halves of the body apart. This action of the muscles presses the lower half of the body down upon the thing which is supporting it—namely, the platform of the weighing-machine—and thus registers, for a moment, an increased pressure.



If we now stand upright again, all these things happen in the reverse order. With a sensitive weighing-machine it is quite easy to see even the effect of raising an arm.

Thus, simply by using our own muscles, we can alter our weight (that is, the pressure we exert on whatever we are standing upon) just as we like. So, obviously, if we jump right off the ground, we have no weight at all while we are in the air.

After all this, we shall find it quite easy to answer the old question: What is the weight of a flying fly? Imagine the fly inside a tumbler on a letter-scale. If it is resting on the bottom of the tumbler, it weighs whatever any respectable house-fly does weigh—say about two grains. And if it flies horizontally across the tumbler, it weighs exactly the same. For it presses on the air with its full fly-weight, and this pressure is transmitted downwards by the air: the balance will show it, if it is sensitive enough.



But, if the fly moves downwards, it becomes lighter. It is easy to see that this is bound to happen; for it would weigh nothing at all if it were to let itself fall straight down, like a freely falling body. And if the fly flies upwards its weight increases, for it adds to its normal weight the extra pressure of its wings on the air.

All these effects depend on the famous 'Third Law of Motion', discovered by Sir Isaac Newton. This Law is the Law of Action and Reaction, and it tells us that Action and Reaction are equal and opposite to each other. If, for example, I strike the table with my fist, the table-top presses against my fist with a force equal and opposite to the force which my fist exerts on the table.

Perhaps the most striking evidence of the Law of Action and Reaction is shown when we try to set a heavy car in motion by pushing it. The car pushes us back just as hard as we push it, and we have to find a firm foothold to resist this pressure. If the ground is very slippery, it is impossible to set the car moving unless we can find something to push firmly against with our feet or body.

But how does the attraction of the Earth come into all this?

When an apple falls off a tree, it does so because the Earth is attracting it. But if the Earth attracts the apple, then, if the Law of Action and Reaction is true, the apple must attract the Earth with an equal force. This is actually the case. It is as though apple and Earth were connected by a stretched rubber band, pulling the Earth at one end and the apple at the other.

So, strictly speaking, the apple does not fall to the Earth. Earth

and apple fall towards one another. But the rate of falling of the two bodies is different. The forces of attraction of each upon the other are the same, but the force on the apple gives it a speed of 32 feet per second at the end of the first second, while the same force on the Earth gives it a speed as many times less as the mass of the apple is less than the mass of the Earth.

The mass of the apple, of course, is immeasurably smaller than that of the Earth. The apple gives the Earth a motion which is so slight that we can safely call it none at all, and therefore it would be ridiculous to say that the apple and the Earth fall towards one another; we can accept with a clear conscience the ordinary idea that it is only the apple which falls.

If, however, it was a question not of an apple, but of a heavenly body large enough to compare in size with the Earth, then the Law of Action and Reaction would make itself felt. For instance, if a body as heavy as the Moon started to fall towards the Earth from close to its surface, the Earth would at once fall towards it also, and in the first second would get up a speed of 4½ inches a second.

The Law of Gravitation—that is, of the mutual attraction of bodies—does not hold good only in the case of planets and moons and suns, but for all bodies without exception. Some of us may perhaps feel rather surprised that we should not be aware, in our everyday lives, of this universal gravitation, in spite of the fact that it moves suns and keeps whole worlds in their eternal paths. We know and can see, of course, that the Earth attracts all objects, but has anyone ever seen two apples, or two persons, or two ships on the sea attracting one another? Why do we notice nothing of the power of gravitation between these objects, and all others as well? Does it not exist, after all?

Yes, it does exist. It has been calculated that every pound weight (no matter of what material) attracts every other pound weight at the distance of a foot with a force about equal to the 1/440,000th

part of a grain. If we change the distance apart of the two masses, or their amount, the force changes too. It is easy to calculate it in any given case. It is equal to

$$\frac{1}{440{,}000} \quad \frac{\text{weight of one mass} \times \text{weight of the other}}{\text{square of distance between them}} \quad \text{grains.}$$

This gives us the force of attraction in grains, if the masses are expressed in pounds and the distances in feet.

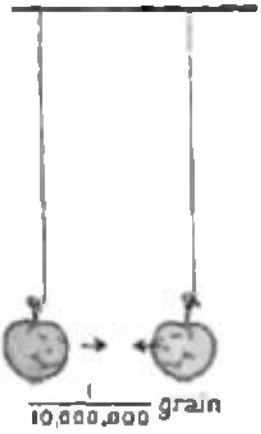
If we work out the calculation with the Earth and the Moon as the two masses, the answer is that our own planet and its satellite

attract one another with a force of 20,000 billion tons. This gigantic force, which is equal to the weight of a billion battleships, keeps the

Moon to its almost circular path round the Earth, and prevents it going off at a tangent into the depths of space. If we had to replace this invisible bond by a material one, we should have to connect the Earth and the Moon by a steel rod about 370 miles in diameter. And if we wanted to replace the attraction of the Sun for the Earth by a similar rod, we should need one 5620 miles in diameter—just about three-quarters of the diameter of the Earth—to be able to stand the pull.

If we turn our attention to earthly objects we find, instead of these huge figures, only the minutest forces—even though the things around us are much nearer to one another than the heavenly bodies. But, of course, they weigh infinitely less.

Here, for instance, are two apples hung up alongside one another 4 inches apart, and therefore attracting one another. But if we calculate the attraction between them, we find that it amounts to only about the ten-millionth part of a grain



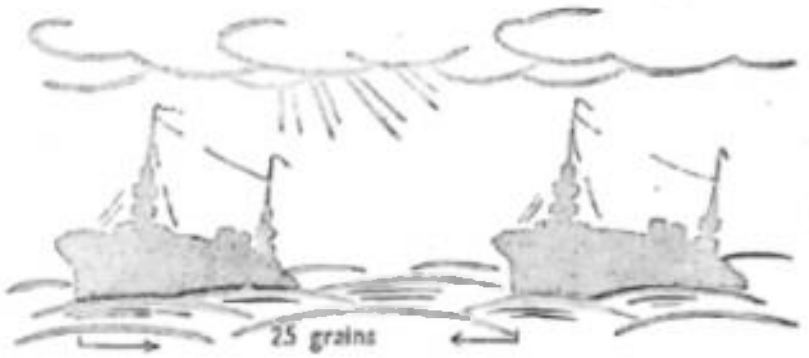
—say the one-hundred thousandth part of the weight of a grain of sand. It is obvious that so minute a force cannot produce any noticeable effect: it is not enough even to bend the thread.

If we calculate the force of attraction between two people a yard apart, we find that it is only one two-thousandth of a grain or so. Although this is some five thousand times more than the attraction

between the two apples, it is still far too little to push a human being along the ground. Of course, if the two people were floating weightless in empty space, exposed to no friction and no resistance, they would—no matter what their own feelings in the matter might be—move slowly towards one another and finally collide. But, since people are always sitting or lying or standing on some kind of a support, they are always subject to a frictional force of some 40 lbs. or so. The two-thousandth of a grain is, of course, powerless to overcome this force; hence it is not surprising that we are entirely unaware of the existence of universal gravitation.

But things are quite different in the heavens. The sun, the stars, the planets, even the moons have gigantic masses, and there is nothing at all, not even air, to resist their motion. And so gravitation is able to exert its full effect.

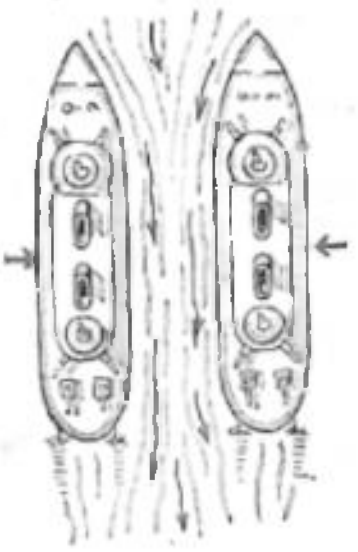
Even if we take the case of two mighty battleships, each weighing 25,000 tons, and a mile apart, we should be wrong if we expected to find that there was a powerful attraction between them, although each ship weighs as much as 250 million apples. But the force with which they attract one another is only about 25 grains.



If the two ships are close together—say 10 yards apart—the attraction will be quite considerable—over one hundred grains' weight. That is nearly a hundredweight, and not to be sneezed at; but it is far from being able to overcome the resistance of the water and draw the two huge masses together.

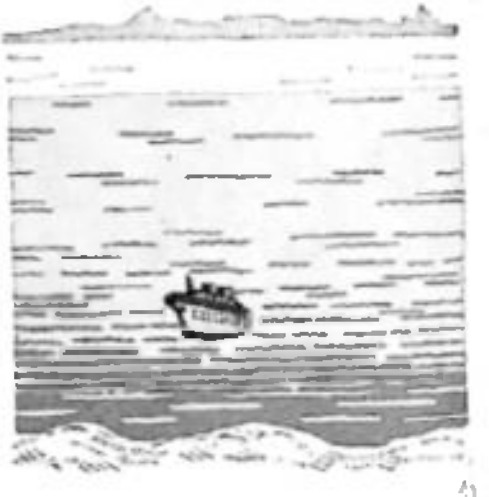
It can sometimes be noticed that two ships travelling along [illegible] close side by side tend to draw nearer together, but this [illegible]

a different reason. It is not gravity that is driving the two ships together; gravity is far too weak. It is the undertow caused by the water rushing between the two ships that draws them together. This only happens when both ships are moving rapidly through the water: if they are lying motionless side by side in still water this sort of attraction is not visible.



Nevertheless the effect of gravitation between quite ordinary masses can be easily seen if very delicate instruments are used to detect it. If a ball of lead is hung from a very delicate balance and carefully counterpoised, and if a truckload of lead bars is run to a point just underneath the lead ball, it can then be noticed that the ball has increased in weight very slightly. Most wonderful of all is the modern 'gravity balance', which is used in the search for minerals. The attraction of the Earth is a little stronger near a point where a mass of heavy mineral lies below the ground.

But let us return to ships. Another question that is often answered wrongly even by old and experienced sailors is this: What is the final resting-place of ships that sink? Do they always reach the bottom, even of the deepest sea?



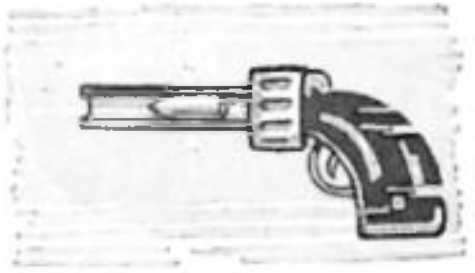
It is a very common notion that such ships remain suspended motionless in the water at some depth or other—namely at the depth at which the water is so dense, as a result of the enormous pressure of the water on top of it, that it is equal in density to the material of the ship. At that point, of course, the ship could not sink any further, since it would come to still denser water, which would drive it upwards again.

This notion appears fairly plausible, for the pressure in the depths of the Ocean is enormous. At a depth of 10 yards water exerts a pressure of 1 atmosphere, or about 15 lbs., on every square inch of a sunken body, and this pressure increases by an equal amount for every 30 feet increase in depth. Now, in many places, the Ocean has a depth of several miles; the deepest hollow in the Pacific is actually over 6 miles below the surface. In it, the pressure must be about 1000 atmospheres, or nearly 7 *tons*, to the square inch.

The marine explorer John Murray once tried wrapping some glass tubes, sealed up at both ends, in a cloth, and then lowering them to a great depth in the sea. When the package was pulled up again, a snow-like mass was found in the cloth; this was the glass, which had been ground to powder by the tremendous pressure.

Wood, after being sunk into the depths, was so compressed that it would not float on water; it had become as dense as stone.

Here is another illustration of how immense the pressure is. Imagine a revolver at the deepest point of the Ocean—30,000 feet or more below the surface. What happens if the trigger is pulled? The water-pressure of 7 tons per square inch greatly exceeds the pressure of the gas produced by the explosion of the powder, so that the bullet cannot escape from the barrel. Nor can the barrel burst, because the pressure of the water will prevent this. So the revolver just won't go off!



Now to return to our problem of the sunken ships. At first sight it would certainly seem likely that the tremendous pressure in the depths of the Ocean might make the water so dense that even very heavy objects could not sink in it—just as a lump of iron will

not sink in a basin of mercury. However, this notion is entirely wrong. Water, like all liquids, is almost 'incompressible'—that is to say, it cannot be squeezed by any pressure, however great, into a space much smaller than it normally occupies. A pressure of 1 atmosphere only causes water to shrink by 1/22000th of its volume. To make water as dense as iron, it would require a pressure of about 44,000 atmospheres, or a depth of 28 miles; and nowhere on Earth is such a depth to be found. Even in the deepest oceans the greatest increase in density is not more than 5 per cent. And so there can be no doubt whatever that every ship that sinks reaches the bottom of the sea.

But this quality which is not to be found in the deepest ocean can nevertheless be observed on the surface of an inland sea. The water of the Dead Sea is so heavy that no one could possibly drown in it. The cause of this density is the extraordinary amount of salt which it contains. Ordinary sea-water contains only 2 to 3 per cent

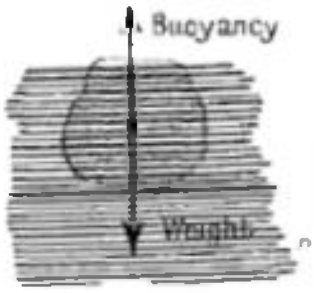
of salt, but that of the Dead Sea contains about 24 per cent. One quarter of its weight is salt. Hence the water is so heavy that, when you bathe in it, you swim *on* the water rather than *in* it. You can

float at full length, fold your arms, and bob about like a cork. If you try to dive in head first you do not enter the water further than your chest. It is difficult to swim on your back because your feet will not go into the water deep enough; only your heels are under the water and so you cannot strike out properly against it.

Sick people who take brine baths have the same experience, for if the baths are very strong they find it impossible to stay under the water. There is a story that a lady who was sent by her doctor to

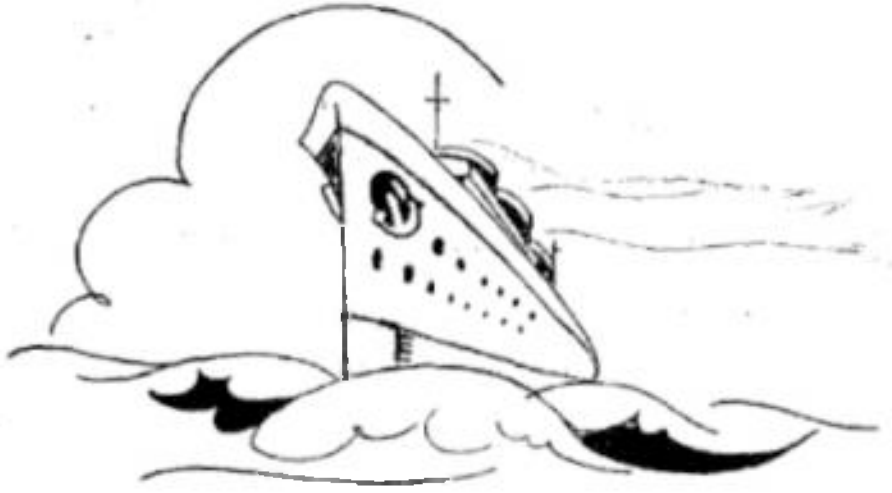
a bathing establishment to take baths of this kind was highly indignant because the water pushed her out of the bath. She was evidently blaming the proprietor of the baths rather than the laws of physics!

The law of floating bodies, known as the 'Principle of Archimedes', is responsible for all these curious happenings. Every object immersed in a liquid becomes lighter by the weight of the liquid which it displaces. It is for this reason that an object floats in a liquid, if it is lighter, bulk for bulk, than the liquid. It sinks in the liquid



only just far enough for it to displace a bulk of liquid equal to its own weight. Then, you may say, it has lost all its weight and so cannot sink any further. But, of course, actually the liquid is pushing it upward with a force—' buoyancy ', as it is called—equal to the weight of the object and acting in the opposite direction. The body is in equilibrium under the two opposing forces, and so floats.

A steamer does not float at the same depth in all waters. Its waterline is lower in salt water than in fresh. There is a law that

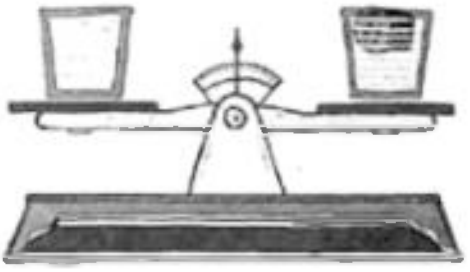


all vessels must carry what is called the ' Plimsoll Mark ', which shows the maximum depth to which they may be loaded. This is required to show the waterline of the steamer when it has its maximum load on board, and when it is floating in various waters. It looks like this:

(Fresh water)
(India, summer)
(Summer sea)
(Winter sea)
(Winter, North Atlantic)

With the same load, it floats a good deal higher out of the water in the cold, dense sea-water of the Atlantic in winter, than on arrival in port at the mouth of a great river, where the water is fresh.

People who are not acquainted with the laws of floating bodies are often taken in by the following catch. On each pan of a balance is a pail of water, of equal size and filled to the brim. But in one of the pails a lump of wood is floating. Which pail is the heavier?



People answer this question in all sorts of different ways. One will say that the pail with the wood in it is heavier, because the wood is there in addition to the water. But others take the opposite view, giving as their reason that water is heavier than wood. Actually the pails are exactly equal in weight.

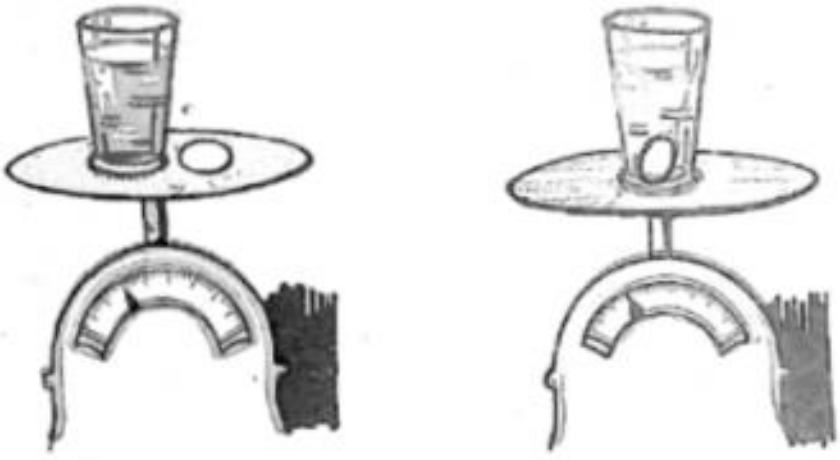
One of them, it is true, has slightly less water in it, for the wood takes up a certain amount of room in the pail. But the water displaced by the wood is exactly equal, according to the laws of floating bodies, to the weight of the wood. So the pail with the wood contains a lesser weight of water which is exactly made up by the weight of the wood. Both pails weigh the same.

Here is another little puzzle concerning the Principle of Archimedes. Place upon a sensitive balance a glass of water, and alongside it an egg, and counterpoise exactly. Then put the egg in the water. What will the balance show?

According to the Principle of Archimedes, the egg becomes lighter when it is put into water, and so one might think that this loss of weight would be shown on the balance. But it is not shown; the balance shows no change at all.

How does this come about? Is the Principle not true after all? Certainly it is true, but we are applying it wrongly: we have only taken one half of it into account, and have forgotten the other. The

egg *does* become lighter in water, for it is pushed upwards by it. But the egg pushes downwards on the water with the same force with which the water pushes it upwards—so says the Law of Action and



Reaction! In this way, the weight which the object immersed in water loses is, so to speak, transferred to the water. The water in the glass becomes heavier by exactly the same amount, and the total weight on the scale does not change.

This is another common catch question: Which is the heavier, a ton of wood or a ton of iron?

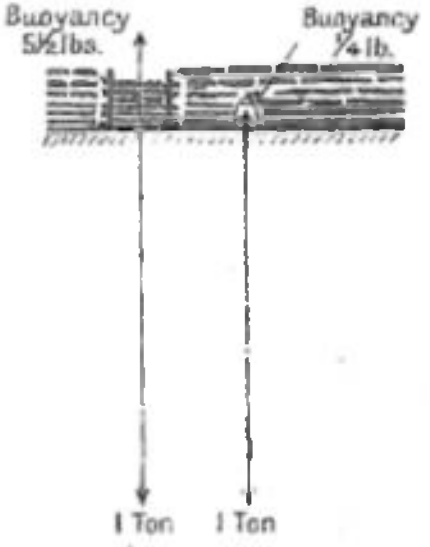
It sometimes happens that someone is trapped into saying that the iron is much the heavier, forgetting that a ton is always a ton.

and equal to 2240 lbs.—unless it is a 'short' ton, equal to 2000 lbs. (Another kind of 'short' ton may be had by going to the right coal-merchant, but its value in pounds is not legally defined!)

Supposing someone answered that the ton of wood was heavier than the ton of iron? That would seem even sillier, wouldn't it? But as a matter of fact this absurd answer would be quite correct, for the following reason.

The Principle of Archimedes holds good not only for liquids, but also for gases. In air, therefore, a body loses weight equal in amount to the weight of the air which it displaces. It is owing to this fact that a balloon or an airship is able to rise from the ground, for they are filled with gases—hydrogen or helium—which are lighter than air.

In order, therefore, to find the true weight of a body, we must take into account the weight which it loses by reason of the buoyancy of the air. In the case of the wood and the iron, the true weight of the wood is equal to a ton, plus the weight of the air which the wood displaces. And the true weight of the iron is equal to a ton, plus the weight of the air displaced by the iron.



But the volume of a ton of wood is about sixteen times as great as the volume of a ton of iron. A ton of wood has a volume of about 2 cubic yards, a ton of iron only about one-eighth of a cubic yard.

And since air weighs about 2¾ lbs. per cubic yard, the difference is about 5¼ lbs. So a ton of wood is heavier than a ton of iron by this amount. Of course, if we wanted to be strictly accurate, we should say that the true weight of a quantity of wood which weighs a ton in air is about 5¼ lbs. greater than that of a quantity of iron which weighs a ton in air.

In ordinary life, of course, we do not notice these effects. But if we could follow the example of one of Jules Verne's heroes and walk about at the bottom of a mine 30 miles deep, we should very soon notice a difference.

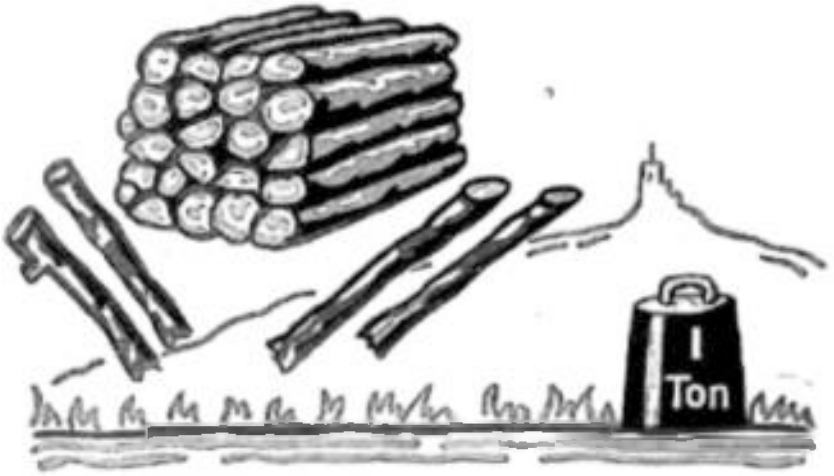
The deeper you go down into the Earth, the greater becomes the pressure, and therefore the density, of the air. It actually increases by a thousandth of its amount for every 26 feet you go down. With

the help of a table of logarithms it is easy to calculate that the pressure at a depth of 30 miles must be more than 400 times as great as at the Earth's surface. This compressed air will be much denser than ordinary air; it will, as a matter of fact, be about half as dense as water, and a little denser than wood. Wood, therefore, will *float* in it.

If we took the ton of iron and the ton of wood down to the bottom of the mine, we should at once notice the effect of the density of the air. The iron, it is true, would lose a good 150 lbs. of its weight, but it would still stay on the ground. But the wood would rise like a balloon, for its buoyancy would be greater than its weight. It would continue to rise up the mine-shaft till it reached a point at which its own density was equal to that of the air.

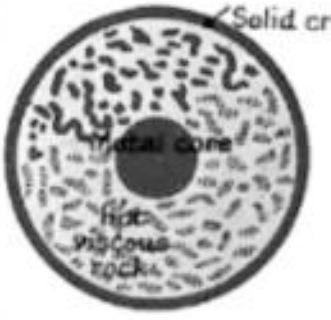
We ourselves, however, would hardly feel as comfortable as Verne's hero is said to have felt. The enormous pressure of 400 atmospheres would be insupportable: the greatest pressure that human beings can stand for a long period without injury is 3 atmo-

spheres, which corresponds to a depth of about 6 miles below the Earth's surface. So, if the Ocean were to dry up, we should just be able to colonize its deepest part.



Human life is likewise subject to a limit as we rise up above the surface of the Earth. Beyond about 16,000 feet the low pressure of the air begins to cause discomfort, and makes it impossible for a man to stay for very long at this altitude. We are all familiar with the fact that airmen and mountain-climbers who go up higher than this altitude have to take oxygen gas with them.

What the inside of the Earth is really like is a problem about which Science cannot tell us very much. It is not even known whether the interior of our planet is solid, or whether it is molten hot. Some people suppose that, beneath a solid crust only about a hundred miles thick, there is a mass of hot, viscous liquid; others believe that the Earth has a very dense, solid core; others, again, say that it is solid right through. No one can say for certain which of these theories is right. The very deepest mines only go down about a mile and a half; the deepest bore-hole is 8,000 feet deep. You can easily see how little this is by looking at a terrestrial globe a yard in diameter. The thickness



of the paper covering on which the map is printed corresponds, more or less, to the greatest depth to which man has penetrated into the Earth. All he has so far succeeded in doing is to scratch the Earth very slightly.

If it were possible to bore a hole like an Artesian well right through the centre of the Earth to its other side, then we should be able to find out all about its inside.

In the eighteenth century learned men such as the mathematician Maupertuis and the philosopher Voltaire were already dreaming of a bottomless well of this kind. The famous popular writer on astronomy, Camille Flammarion, also gave the subject a good deal of attention.

Naturally it will never be possible for mankind to bore such a hole. But that does not prevent our imagining it done, and then wondering: what would happen to a man who jumped into this bottomless pit?

He would fall, faster and faster every second: but after quite a short time the friction caused by the resistance of the air would cause him to get hotter and hotter, and finally to burn up completely. But suppose that we leave out this question of air-resistance and consider what would happen if it did not exist.

The man would fall, ever faster and faster, but he could not crash

on to the bottom of the pit, because it has not got a bottom. When he reaches the centre of the Earth there is nothing to stop him, so he flies straight on; he would be travelling at the terrific speed of 5 miles per second. His enormous impetus will carry him onwards, but from the moment that he passes the centre of the Earth he will no longer be falling, but shooting upwards towards its opposite surface. His speed will, of course, now get less and less, just like that of a ball thrown up into the air. But he will not entirely stop moving until the end of the well, and he will have to grab the edge of the well's mouth at the right moment; otherwise he will fall back again and perform the whole of his strange journey in the opposite direction, arriving back exactly where he started. If he again fails to hold on and thus get out of the well the same thing will happen again. We learn from the science of Mechanics that any solid object would—but for the resistance of the air—go on travelling to and fro in this way for ever and ever.

If the entrance to the well were situated on one of the high tablelands of South America, at, say, 6000 feet above sea level, and the other end came out actually at sea level, a person who jumped in at the South American end would shoot out at the other end at such a terrific speed that he would climb like a rocket more than a mile into the air. But a journey in the other direction would be impossible; he would never reach the mouth of the well at the South American end.

If, however, the two mouths were at equal heights above sea level, it would just be possible to grasp the hand of the man 'falling' upwards and to hold him. For his movement would stop exactly at the mouth of the well.

We can tell by calculation that it would take just 42 minutes

to travel right through the Earth in this way. So we should be able to travel from England to New Zealand in under three-quarters of an hour—and, what is more, at no cost for power whatsoever. It certainly seems a pity that this rapid and convenient means of connection can never be built. A suitable shaft only 2 miles deep would

take about 30 years to construct, and would cost more than half a million pounds. And a tunnel to New Zealand would have to be at least 4000 times longer than this.

This question of straight tunnels on our round Earth is a curious one. Anyone who has travelled through the Simplon Tunnel will surely have observed, or at any rate have been told, that the centre of the tunnel is always wet, even in the middle of summer. This is not so very remarkable in itself. But it does not occur only in the Simplon Tunnel: in all straight tunnels water always collects near the middle, and can only dry up with difficulty on account of the imperfect ventilation. If the middle of the tunnel were lower than

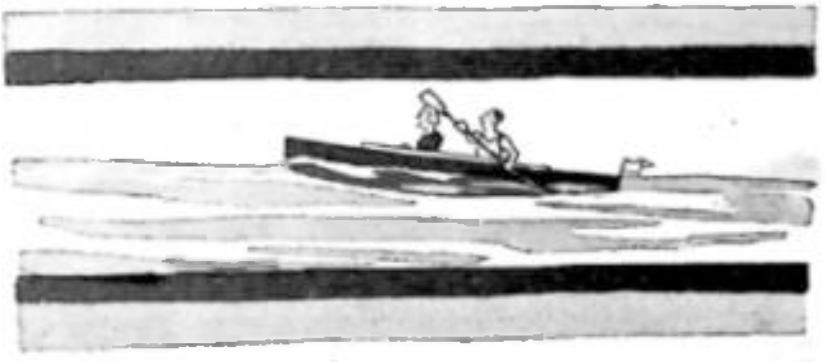
the ends, it would not be surprising for water to collect there, but the effect is noticeable in perfectly straight tunnels.

Let us consider this curious question carefully, taking the case of a tunnel 60 miles long and perfectly and mathematically straight, so that we can look through from one end to the other. We will

suppose the inside to be coated with some waterproof material.

Next, we must get in touch with the Clerk of the Weather and ask him to arrange for a first-class downpour of rain lasting several days. The rain will pour into the tunnel from both sides. As soon as it has stopped and the sun has dried up the surrounding country a little, we will examine the tunnel.

The water has run off and the entrance is perfectly dry. We go further into the tunnel; presently we find it damp underfoot, and the further we go in the wetter our feet become. Soon we cannot walk any further, for the water lies right across the tunnel. But we

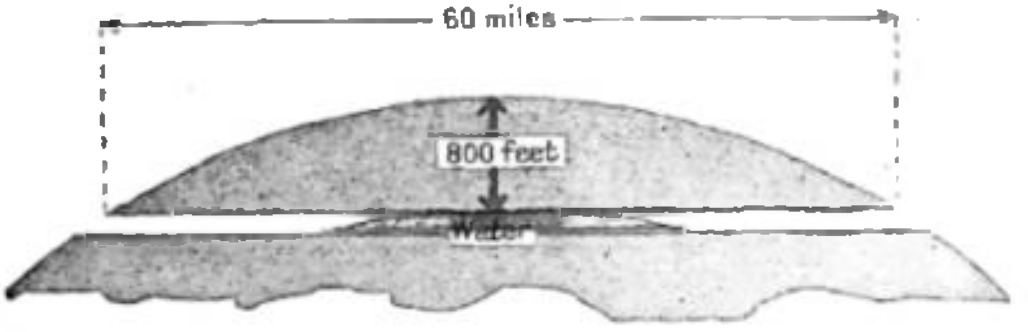


have brought a collapsible canoe with us in case we need it, so how we rig it up and, embarking upon the underground canal, paddle onwards. The water gets deeper and deeper; the nearer we get to the middle of the tunnel, the higher the water level. Soon we have to bend our heads down, and then, as we approach the middle, we

are obliged to give it up. The water fills the tunnel from floor to ceiling.

If we start from the other entrance we find exactly the same state of affairs. The tunnel is filled with water in the middle, and it does not run out, although the tunnel is dead straight from end to end.

A strange business, indeed. But an explanation is not hard to find. The Earth is a round ball, a sphere. Its surface, therefore, is not flat, but everywhere curved. The sea, which appears flat, is also



curved, as indeed our eyes inform us. A free mass of water always settles down and adapts itself to the curvature of the Earth, in such a way that every drop of water on the surface is at an equal distance from the centre of the globe. The water in the tunnel also does this. But the tunnel does not follow the curvature of the Earth, for it is built with mathematical accuracy to be dead straight. Hence the water curves upwards in the tunnel.

The surface of the Earth, of course, if it is 'flat' above where the tunnel lies, also curves in an arch over the straight tunnel, the centre of which lies nearer to the centre of the Earth than its ends. As a matter of fact, if we started to dig down from the surface of the Earth to the tunnel near its centre, we should have quite a long way to go before we burst through into it. We should find that the middle of the tunnel was a good 800 feet below the surface of the Earth. So it is not at all surprising that the water should collect at the deepest point it can find, and should show no disposition to climb up towards the entrances of the tunnel.

What does water weigh? That depends upon its temperature,

say those who have paid attention during the school Physics lesson; and they are right, of course. Water is heaviest at 4 degrees Centigrade, or about 39 degrees Fahrenheit. At this temperature a cubic metre weighs exactly 1000 kilograms. But this is only when the water is at sea level. If we carry it up to the top of a high mountain it becomes somewhat lighter, since the attraction of the Earth, which is the cause of weight, becomes smaller as one goes further away

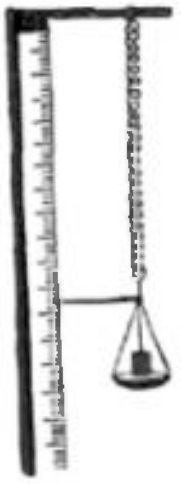
from the Earth's centre. This loss of weight makes so little difference, even on the highest mountains, that it can hardly be detected by experiment. Even Professor Piccard, who climbed to a height of 50,000 feet in his giant balloon, could hardly have detected any loss of weight. For what is 50,000 feet, compared with the 4000 miles which separate us from the centre of the Earth?

If we imagine Piccard's giant balloon, 100 feet in diameter, to be the Earth, then the height which he reached in exploring the stratosphere would be less than 2 inches. It is not possible to show this small distance to scale on the drawing; it is too minute as compared with the balloon.

The loss of weight which can occur at the heights we are able to reach is thus very slight indeed; but it exists nevertheless. The delicate 'gravity balance' of which we have spoken can detect it easily.

Even when water is not raised above the Earth's surface its weight is not constant. It depends upon its geographical position. A cubic foot of water weighs a quarter of a pound or so less at the

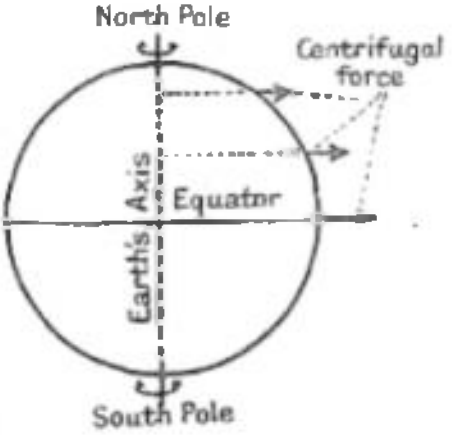
Equator than at the North Pole. We cannot, of course, determine this difference in weight by means of an ordinary pair of scales, for the weights we use would be reduced in proportion. We must therefore use a spring balance, in which the weight is indicated by the amount by which it stretches a spring.



This surprising difference in weight at the Pole and at the Equator has a very simple cause, but one which few people realize. The Earth, as we all know, turns once in 24 hours round an axis which passes through its two poles. It is like a gigantic top, and a centrifugal force is produced which is always directed outwards from the Earth's axis. At the Equator this acts in direct opposition to the force of gravity, and so causes a reduction in weight.

(We must not omit to mention that the surface of the Earth at the Equator is further away from its centre than at the Poles; for the Earth is not perfectly spherical, but flattened like an orange. Hence, for this reason also, the force of gravity is less at the Equator than at the Poles.)

The amount of this centrifugal force depends, on the one hand, upon the rate of rotation of the Earth, and, on the other, upon the vertical distance of the point in question from the axis round which the Earth is turning. It does not exist at all at the Poles, for these lie on the axis itself, and hence are zero distance away from it. The centrifugal force is strongest at the Equator, for here the distance from the axis of rotation is greatest, being half the diameter of the Earth.



The strength of this centrifugal force at the Equator amounts to about 4 ounces on a cubic foot of water—which weighs almost exactly 1000 ounces. It makes the water 4 ounces lighter than it ought to

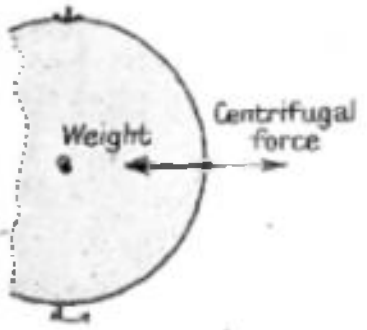
be. In our latitude it amounts to about 2½ ounces; at the Poles it is zero, as we have just explained.

Thus a fat Eskimo weighing 200 lbs. would lose nearly a pound in weight if he travelled to the Equator. But it would be no use for all the fat people in our part of the world, who are tired of being

too heavy, to travel to the Equator for a course of centrifugal slimming. What they lost in weight on the outward journey they would at once put on again on the return journey. Of course, the same thing often happens when people take an expensive course of baths at some fashionable resort; but they at least enjoy both a short period of elegant slimness and the pleasure of putting on weight again by eating too much. Centrifugal slimming has neither of these advantages; the moment you are back home you are also back at your former weight.

If we could find a way to speed up the rotation of the Earth, the loss of weight due to centrifugal force might become very perceptible indeed. Let us try and imagine what it would be like.

We know that the centrifugal force at the Equator amounts at present to about 4 parts in 1000 of the weight. Let us make a small calculation. The easy-going old Earth takes 24 hours to turn only once round itself. Imagine that we succeed in persuading it to move 16 times as fast, so that it revolves once in an hour and a half. A curious thing happens; this increase of speed also increases the centrifugal force to an enormous extent: not merely 16 times, but 16 times



again—that is, about 250 times. So the decrease in weight of 4 ounces per 1000 becomes 250 times as much—that is, 1000 ounces. In other words the centrifugal force at the Equator now exactly balances the attraction of the Earth, and nothing has any weight!

The fact that the days and nights would each be only three-quarters of an hour long would not be so difficult to get used to. But our unfortunate fellow-creatures in Borneo and Brazil would not have time to get used to anything. They would be drifting about, entirely weightless, and the least draught would carry them over the clouds and blow them north, south, east and west! If they travelled north or south they would move towards the Poles.

But since, in our part of the world, the centrifugal force is only half as effective as at the Equator, weight would still exist here, and the people drifting towards us in the clouds from the Equator would be pulled down to Earth again.

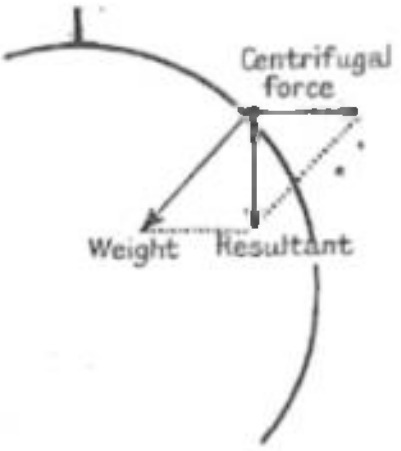
So we should have a rapid and thorough process of migration by air from the Equator towards the temperate zones. All the brown

and black races of the Tropics would come sailing over and raining down upon us.

Z1996

These exotic guests, however, would not find our part of the world very comfortable, even supposing they had stood the journey well. It is true that we should have retained a considerable share of our normal weight, but this would no longer act vertically down-

wards, in the way to which we are accustomed. Its line of action would slope towards the north. The reason for this is that the centrifugal force and the force of gravity would combine to form a force which no longer pointed, as gravity by itself does, towards the centre



of the Earth; because the direction of the centrifugal force is not towards the centre, but vertically towards the axis, of the Earth.

So, in order to keep our balance, we should have to stand at a slant, like a cyclist turning a corner, or as if we were trying to keep our feet in a hurricane blowing from the north. People not usually very agile would easily be able to climb up the north side of a house, provided they remained standing, like a fly climbing up a wall. All motor-cars travelling northwards would be pulled up, stopped, and pushed backwards by this mysterious force.

Only the Poles would be spared the effects of this overpowering centrifugal force. The polar bears would continue to trot quite comfortably about in the snowfields, and, at most, would be rather surprised to see the sun moving so quickly round the sky! But if they got too far away from the Poles on the slippery ice, they would find a mysterious force pushing them southwards.

Centrifugal force does not act only upon men and animals. The air, too, would be greatly upset by it. The weightless air would rise up at the Equator; this would result in a vacuum, into which air would rush from north and south. So terrific winds would be blowing in the upper regions of the air *away* from the Equator, while, down

below, equally terrific polar storms would be blowing *towards* Equator. Everything on earth that was not firmly anchored do would be carried along.

The seas of the Tropics would be emptied over Europe Australia. Siamese elephants would rain down on Moscow, Brazilian towns would thunder from the clouds on to New Y

So we had better be careful about speeding up the Ear ever we find a way of doing it!

With this terrifying vision we will bring our stroll through Pl to an end. The laws of Nature are all right as they are. Any ch would bring about a catastrophe, for the space allotted to us to in is too small.

From 6 miles below sea level to 3 miles above it—that is all space on our Earth which is peopled—and all which can be peo —by living beings. As compared with the whole of the Earth, it thinner than the skin of an apple, but above it and below it the is death.